IS 6134-3 (1973): Methods of Measurements on Microwave Tubes, Part III: Amplifier tubes [LITD 4: Electron Tubes and Display Devices]

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(Reaffirmed 2003)

Indian Standard
METHODS OF MEASUREMENTS ON MICROWAVE TUBES
PART III AMPLIFIER TUBES

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Indian Standard
METHODS OF MEASUREMENTS ON MICROWAVE TUBES
PART III AMPLIFIER TUBES

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Indian Standard
METHODS OF MEASUREMENTS ON MICROWAVE TUBES
PART III AMPLIFIER TUBES

0. FOREWORD

0.1 This Indian Standard (Part III) was adopted by the Indian Standards Institution on 28 May 1973, after the draft finalized by the Electron Tubes Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard (Part III) deals with methods of measurements of characteristics of microwave amplifier tubes which are common to the family of amplifier tubes. The measurements described in this standard are either in addition to or alternate to those given in IS : 6134 (Part I/ Sec 1)-1971*. Specific types of amplifier tubes shall be dealt with separately to which this standard and IS : 6134 (Part I/Sec 1)-1971* shall form necessary adjuncts.

0.3 This standard is based on IEC Pub 235-2 'Measurement of the electrical properties of microwave tubes, Part 2 General measurements' issued by the International Electrotechnical Commission.

0.4 This standard is one of a series of Indian Standards on electron tubes. A list of standards so far published in this series is given on page 16.

0.5 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960†.

1. SCOPE

1.1 This standard (Part III) deals with methods of measurements of characteristics of microwave amplifier tubes which are common to the family of amplifier tubes.

*Methods of measurements on microwave tubes: Part I General measurements, Section 1 General conditions and precautions for measurements.

†Rules for rounding off numerical values (*revised*).

1.1.1 Specific types of amplifier tubes, such as forward-wave amplifier tubes and klystron amplifier tubes are dealt separately.

2. TERMINOLOGY

2.0 For the purpose of this standard, the terms and definitions covered in IS : 1885 (Part IV/Sec 3)-1970* shall apply.

3. GENERAL CONDITIONS

3.0 The provisions of IS : 6134 (Part I/Sec 1)-1971† shall apply.

4. POWER GAIN

4.1 Theory — The power gain, G, of a microwave amplifier tube is a logarithmic measure of power amplification attained with that tube. It is expressed in decibels and given by the following equation:

$$G = 10 \log \frac{P_2}{P_1}$$

where

P_2 = output power in watts, and

P_1 = driving power in watts.

4.1.1 In most microwave amplifier tubes, if the operating conditions (that is, beam current and voltage, frequency, etc) are fixed and only the driving power is increased, the output power is at first proportional to the driving power and thus the gain is constant. As the driving power is further increased, the amplifier tube ceases to be a linear device and the gain becomes dependent upon the driving power. It is, therefore, always necessary to state the power level (that is, output power) at which the gain is measured.

4.2 Available Power Gain at Specified Output Power — The tube is connected to a transmission system coupled to a suitable power measuring circuit (*see* Fig. 1), terminated by a matched load and operated in accordance with the manufacturer's instructions. The available driving power required to obtain a specified output power (for example nominal power) at the driving frequency is determined, and the available power gain is computed from the formula given in **4.1**, where P_1 now represents available driving power. The result is expressed in decibels.

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*Electrotechnical vocabulary: Part IV Electron tubes, Section 3 Microwave tubes.

†Methods of measurements on microwave tubes: Part I General measurements, Section 1 General conditions and precautions for measurements.

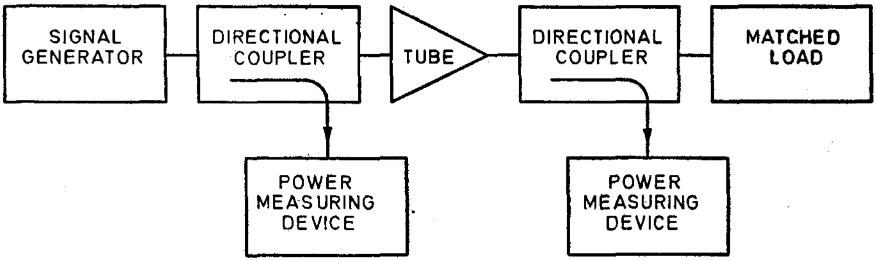


FIG. 1 TYPICAL BLOCK DIAGRAM OF A CIRCUIT FOR THE MEASUREMENT OF GAIN

4.2.1 During this measurement, the tube operating conditions (for example, beam voltage and tuning) are either:

a) maintained at stated values, or
b) adjusted to provide maximum gain.

In the case of (b), the gain obtained is called the maximum available power gain.

4.3 Small Signal Gain — The tube is operated as in **4.2**. The available driving power is gradually reduced until there is no further change in gain. Small signal gain is then computed from the formula given in **4.1**.

4.3.1 During this measurement, the tube operating conditions (for example, beam voltage and tuning) are either:

a) maintained at stated values, or
b) adjusted to provide maximum gain.

In the case of (b), the gain obtained is called the maximum small signal gain (synchronous gain).

4.4 Gain Linearity — Under consideration.

5. VARIATION OF GAIN WITH FREQUENCY

5.1 Instantaneous Bandwidth

5.1.1 The tube is operated in accordance with the manufacturer's instructions, in the circuit shown in Fig. 2. All normal operating adjustments should be optimized over the frequency interval considered.

5.1.2 While the driving signal is swept through the required frequency interval the variations of gain are observed on the screen of a calibrated oscilloscope.

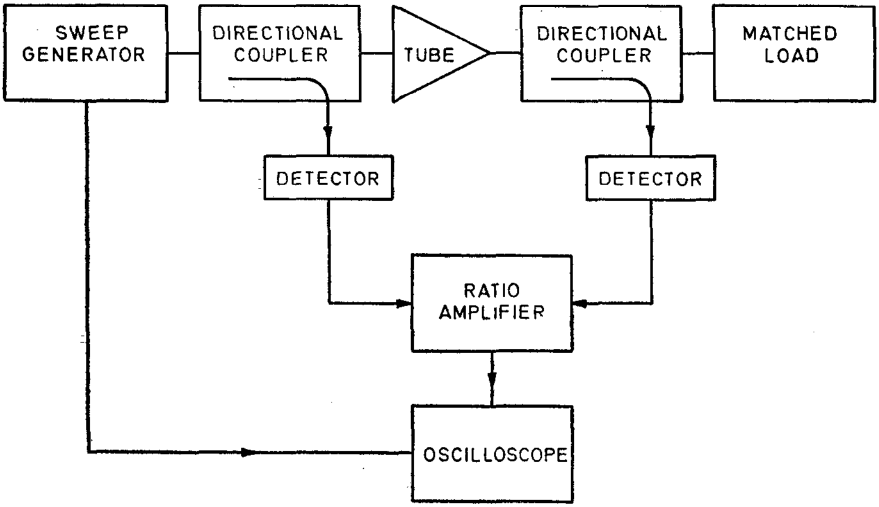


Fig. 2 Block Diagram of a Circuit for the Measurement of Variation of Gain with Frequency

5.1.3 From the gain *versus* frequency characteristic, the frequency interval over which the gain remains within the stated limits is measured.

5.1.4 *Precautions* — The following precautions shall apply:

a) Available driving power shall not vary by more than a stated fraction (usually $\pm 0{\cdot}5$ dB) in the swept frequency interval;

b) The sweeping frequency should be much lower than the bandwidth of the tube and ratio amplifier, but high enough to exclude any thermal drift effects; and

c) Matched pair of directional couplers and detectors, calibrated over the required frequency interval, should be used for this measurement.

5.2 Gain Flatness

5.2.1 The tube is operated as in **5.1.1** and **5.1.2**.

5.2.2 The difference between maximum and minimum values of the gain within the stated frequency band (*see* Fig. 3) which is a measure of gain flatness is computed from the gain *versus* frequency characteristic.

5.2.3 *Precautions* — The precautions specified in **5.1.4** shall apply.

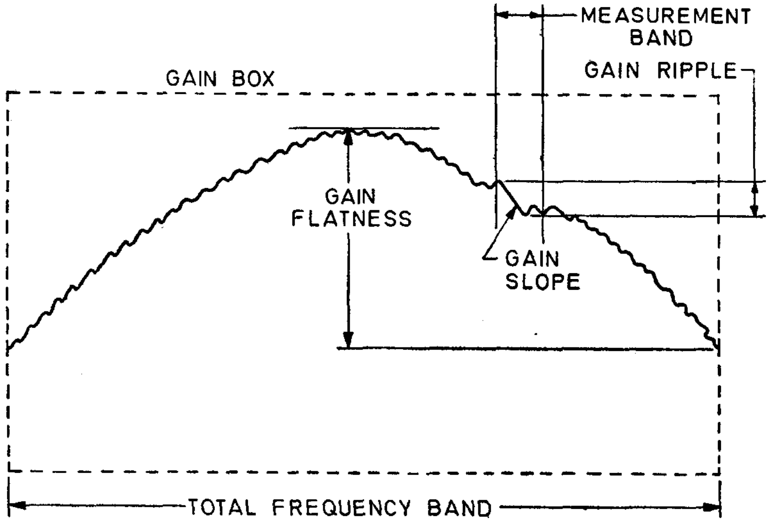


FIG. 3 VARIATION OF GAIN WITHIN A FREQUENCY BAND

5.3 Gain Ripple

5.3.1 *Theory* — The gain *versus* frequency characteristics of a microwave amplifier tube may show ripples and irregularities which are caused by internal reflections (*see* Fig. 3).

5.3.2 *Measurement* — The tube is operated as in **5.1.1**. The frequency of the driving signal is swept over a stated frequency interval which is small compared with the total frequency band. The variations of gain within the measurement interval are observed on the screen of a calibrated oscilloscope. The measurement is repeated as required throughout the total frequency band.

5.3.3 The gain ripple is to be computed from the gain *versus* frequency characteristic in one of the following manners [*see* **13.3.7** of IS : 1885 (Part IV/Sec 3)-1970*]:

a) As the difference between the maximum and minimum values of power gain over a given frequency increment about a stated frequency, or

b) As the maximum difference in power gain between adjacent peaks and valleys in the gain *versus* frequency characteristic at the most unfavourable part in the total frequency band (operating frequency range).

*Electrotechnical vocabulary: Part IV Electron tubes, Section 3 Microwave tubes.

5.3.4 *Precautions* — The precautions specified in **5.1.4** shall apply.

5.4 Gain Slope

5.4.1 The measurement procedure shall be as given in **5.3.2.**

5.4.2 The maximum slope expressed in dB per MHz, is computed from the gain *versus* frequency characteristic in the stated frequency interval.

5.5 Gain Box

5.5.1 The tube is operated as in **5.1.1.** While the driving signal is swept through the required frequency range, power supply and environmental conditions are simultaneously varied through the stated range of values and variations of gain are observed on the screen of a calibrated oscilloscope.

5.5.2 From the observed gain *versus* frequency characteristic, it is to be verified that all gain values are within a stated gain box (Fig. 3).

NOTE 1 — For convenience, a recorder is often used so that maximum gain excursions are easily observed.

NOTE 2 — When it is difficult to make the measurements with total simultaneity, the gain box may be optionally separated into parts for particular measurements. Each part would include maximum variations in gain caused by the change in a definite parameter which occurs when all other variable parameters are so adjusted as to produce maximum change in gain as the particular parameter is varied throughout its stated range. Since the sum of variations so measured will generally exceed the value measured under simultaneous variation of all parameters, such separation of the gain box into parts shall be at the option of the tube manufacturer.

For example, since it is difficult to vibrate the tube and subject it to the environmental temperature variations simultaneously, it may be desirable to measure the gain box for simultaneous variation of everything but temperature (for which the gain box value is A), and again measure with all parameters varied without vibration (for which the gain box value is B). The sum of the gain boxes so measured should be less than the stated gain box, so that $A+B$ is less than C the stated gain box. The value of $A+B$ will in all cases be greater than the value of the gain box measured with simultaneous variation of all quantities.

5.5.3 *Precautions* — The precautions specified in **5.1.4** shall apply.

6. OUTPUT POWER

6.1 Fundamental Output Power

6.1.1 The tube is operated in accordance with the manufacturer's instructions, in the circuit shown in Fig. 4. Filters are used before the power measuring device in order to eliminate harmonics which may be generated in the tube. These filters should be so chosen that harmonic transmission is sufficiently small, relative to the fundamental transmission.

6.1.2 The indication of the power measuring device multiplied by a factor that takes into account the attenuation introduced by the directional coupler and the filter (on the output side), is a measure of the fundamental output power.

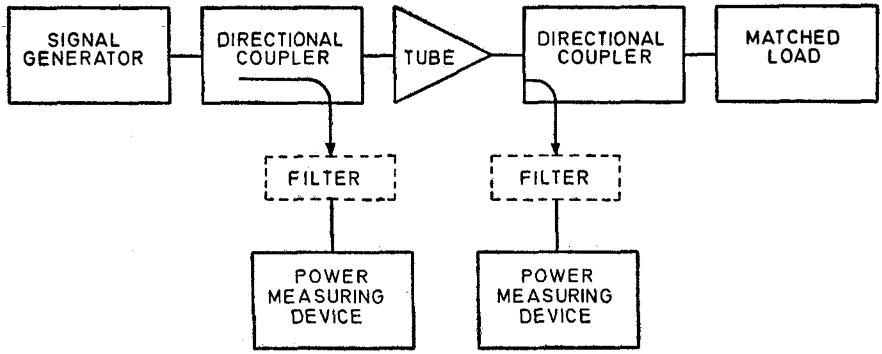


FIG. 4 BLOCK DIAGRAM OF A CIRCUIT FOR THE MEASUREMENT OF OUTPUT POWER

6.1.3 *Precautions* — The following precautions shall apply:

a) The signal source should have a negligible harmonic content, and should be sufficiently well matched so that no reflections of harmonic power take place in the input line; and

b) The filters should preferably not reflect harmonic power, but should absorb it as completely as possible.

6.2 Saturation Power

6.2.1 *Theory* — If the tube operating conditions (that is, beam current and voltage, frequency or frequency band) are fixed, and only the driving power is increased, the output power also increases at first. At a certain value of the driving power, the output power is at its maximum value and the tube saturates. When the tube is driven beyond the saturation point, the output power does not increase any further but may decrease.

6.2.2 *Measurement* — The tube is operated as in **6.1.1**. The driving power is gradually increased and the fundamental output power measured, till the latter reaches its maximum value. The maximum observed fundamental output power is the saturation power.

6.2.3 During this measurement, the beam voltage and/or tuning are either:

a) maintained at a stated value, or

b) adjusted to provide maximum small signal gain, or

c) adjusted to provide maximum output power at each value of driving power.

In the case of (c) the saturation power observed is called the optimum saturation power.

6.2.4 The precautions specified in **6.1.3** shall apply.

6.3 Harmonic Output Power

6.3.1 The tube is operated under stated conditions. By the use of suitable band pass, band-reject or tunable filters, the output at each harmonic of the fundamental frequency is measured in the absence of all others.

6.3.2 The harmonic output power is usually expressed in dB below the fundamental frequency output power for each of the stated harmonic frequencies.

NOTE — Since the impedance presented to the output structure by the transmission and load resistance at the harmonic frequencies is a complicated function of the multiple modes of propagation which may exist, the results of this measurement are only indicative.

6.3.3 *Precautions* — The following precautions shall apply:

a) The signal source should have a negligible harmonic content, and should be sufficiently well matched so that no reflections of harmonic power take place in the input line.

b) The filters should preferably absorb power at the undesired frequencies as completely as possible, rather than reflect it.

c) The harmonic content of the beam of a fully saturated high-power amplifier is very large. The current for each harmonic may be only about 1 dB lower than that of the previous harmonic. Thus even the 10th harmonic may have beam power only 10 to 15 dB below the fundamental. Since many filters have higher pass-bands which are harmonically related to their fundamental pass-band frequencies, it may be necessary to calibrate their attenuation at very high harmonic frequencies to avoid errors due to harmonic power other than that being measured. Similar precautions may be necessary in the case of band rejection filters. A suitable cross-check of the measurement is derived from measurement of the output circuit impedance at the fundamental and harmonic frequencies. These impedances can be used in conjunction with beam current terms to predict the probable magnitude of the harmonic power.

7. INPUT AND OUTPUT REFLECTION COEFFICIENT OR VSWR

7.1 Operating (or Hot) Reflection Coefficient or VSWR

7.1.1 *Input Reflection Coefficient or VSWR* — The tube is operated in accordance with the manufacturer's instructions in the circuit shown in Fig. 5. The matching elements, if provided in the tube mount, are adjusted to achieve minimum VSWR under stated conditions. A suitable filter is used before the reflected power detector in order to eliminate harmonics which may be generated in the tube. Since the result of the measurement may depend on the incident power, this power should be suitably measured and its value stated.

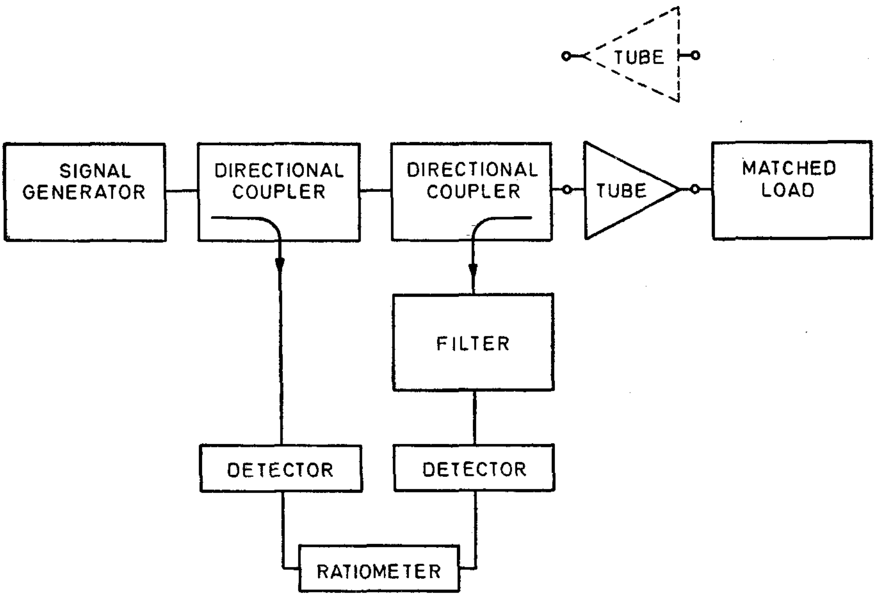


FIG. 5 BLOCK DIAGRAM OF A CIRCUIT FOR THE MEASUREMENT OF INPUT AND OUTPUT REFLECTION COEFFICIENT OR VSWR

7.1.1.1 The modulus of the reflection coefficient is obtained as the square root of the ratio of the reflected to the incident power. The voltage standing-wave ratio, s, is calculated from the following formula:

$$s = \frac{1 + |\underset{\sim}{r}|}{1 - |\underset{\sim}{r}|}$$

where

$\underset{\sim}{r}$ is the reflection coefficient.

7.1.1.2 An alternative method is the direct measurement of the voltage standing-wave ratio and the position of the voltage minimum with a standing-wave detector.

7.1.1.3 *Precautions* — The matched load shall be capable of dissipating the full output power of the tube. The filters should preferably absorb power at the undesired frequencies as completely as possible, rather than reflect it.

7.1.2 *Output Reflection Coefficient or VSWR* — This measurement is made as in **7.1.1** with the tube reverse as shown by the dotted line in Fig. 5.

NOTE 1 — This measurement is necessary for tubes in which gain ripple shall be kept to a very low value and for which short-circuit stability is essential.

NOTE 2 — In certain cases, because of amplified reflections from within the tube, the reflected power may be equal to or greater than the incident power. VSWR measurements are then ambiguous and, therefore, measurement of the reflection coefficient is preferred. In this case, the modulus of the reflection coefficient is greater than unity.

7.2 Cold Reflection Coefficient or VSWR — The procedure for these measurements is the same as described in **7.1.1** and **7.1.2** except that the tube is cold. For these measurements, the filter is not necessary.

8. AMPLIFIER LOSS

8.1 Cold Loss

8.1.1 Before the start of the measurement, the matching elements, if provided in the tube mount, are adjusted to achieve minimum VSWR at the input and output of the tube under operating conditions.

8.1.2 Cold loss is then measured in the direction from the input to the output terminal, or *vice-versa*, by a substitution method, for which a suitable circuit is shown in Fig. 6A. With the tube in place, the signal generator is adjusted to provide a convenient deflection of the indicator. This value and the setting of a calibrated attenuator are noted. The tube is then replaced by a link of known loss and the attenuator is adjusted to provide the same indicator reading. The cold loss is obtained as the difference between the two settings of the attenuator plus the value of the loss of the link. It is expressed in decibels.

8.1.3 *Precautions* — Since the loss may have a very high value in making this measurement, care should be taken to avoid radiation coupling between input and output of the tube.

8.2 Operating Loss

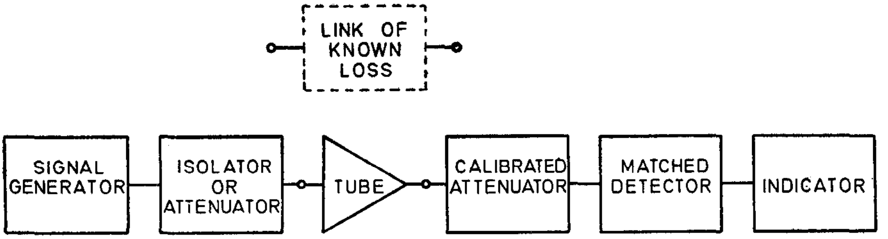
8.2.1 The tube is operated in accordance with the manufacturer's instructions. The beam voltage may be required to be set within a stated range, either:

a) to cause minimum operating loss, or

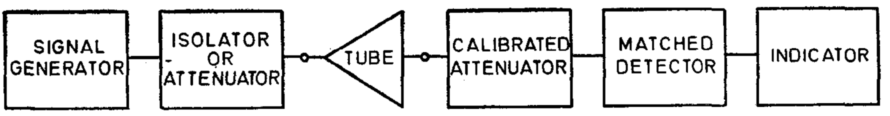
b) to provide optimum operating performance.

8.2.2 Matching elements, if provided in the tube mount, are adjusted to achieve minimum VSWR at the input and output of the tube under operating conditions.

8.2.3 Operating loss is then measured in the direction from the output to the input terminal, by the substitution method described in **8.1** and Fig. 6B.



6A Cold Loss



6B Operating Loss

FIG. 6 BLOCK DIAGRAM OF A CIRCUIT FOR THE MEASUREMENT OF AMPLIFIER LOSS

9. PHASE SENSITIVITY TO VOLTAGE OR CURRENT

9.1 Theory — Most microwave amplifier tubes are electrically very long, and therefore, even small changes in operating voltages may cause detectable phase shifts of the output signal.

In certain classes of microwave amplifier tubes (for example, amplitrons) with a flat voltage-current characteristic, it is preferable to relate phase shifts to operating current instead of operating voltage.

9.2 Measurement — The tube is operated at a stated input power level and in accordance with the manufacturer's instructions. The difference in phase between the output power and the driving power is measured as a function of the voltage applied to a stated electrode (for example, the beam voltage) or the current of that electrode. The phase sensitivity is then derived as the rate of change of the phase difference with respect to the voltage (or current) of the stated electrode. It is expressed in radians per volt (or per ampere) or in degrees per volt (or per ampere).

NOTE — The phase sensitivity of the tube under low level drive conditions may be different from the phase sensitivity near saturation, because of the influence of AM/PM conversion.

10. AMPLIFIER STABILITY

10.1 Theory — Under certain signal source and load impedance conditions and/or beam conditions, it is possible that oscillations may occur in a microwave amplifier tube. Such oscillations are called spurious oscillations.

10.2 Short-Circuit Stability

10.2.1 The tube is operated in accordance with manufacturer's instructions, in the circuit shown in Fig. 7.

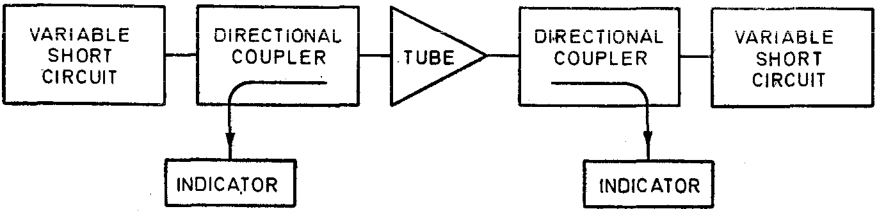


FIG. 7 BLOCK DIAGRAM OF A CIRCUIT FOR THE MEASUREMENT OF SHORT-CIRCUIT STABILITY

10.2.2 The beam voltage is swept over a stated range. The input and output short-circuit terminations are moved in such a way that for any position within a range of at least half a wavelength of one of the terminations, the other is moved through at least half a wavelength. During this operation, observations are made at the input and output for indication of spurious power.

10.2.3 If the observed values of spurious power are below the stated levels, the tube is considered to be short-circuit stable.

10.2.4 *Precautions* — The following precautions shall apply:

a) The band-width of the directional couplers and power detectors shall be sufficient to permit detection of oscillations, and

b) It is necessary to differentiate between noise and spurious oscillation output.

10.3 Mismatch Stability

10.3.1 The tube is operated in accordance with the manufacturer's instructions, in the circuit shown in Fig. 8. The beam voltage is swept over a stated range. The input and output terminations of stated mismatch are moved in such a way that for any position within a range of at least half a wavelength of one of the terminations, the other is moved through at least half a wavelength. During this operation, observations are made at the input and output for indications of *rf* power.

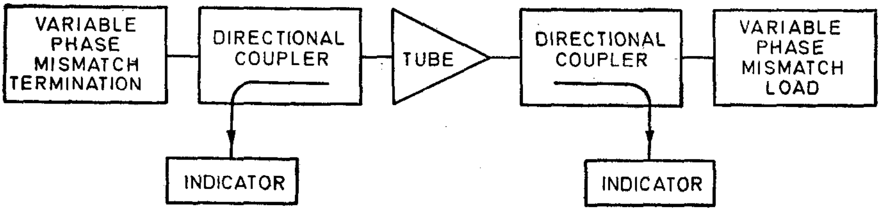


FIG. 8 BLOCK DIAGRAM OF A CIRCUIT FOR THE MEASUREMENT OF MISMATCH STABILITY

10.3.2 If the observed values of the *rf* power are below the prescribed levels, the tube is considered to be mismatch stable.

10.3.3 *Precautions* — The precautions specified in **10.2.4** shall apply.

11. NONLINEARITY — Under consideration.

INDIAN STANDARDS

ON

MICROWAVE TUBES

IS:

1885 (Part IV/Sec 3)-1970 Electrotechnical vocabulary: Part IV Electron tubes, Section 3 Microwave tubes

1885 (Part IV/Sec 5)-1972 Electrotechnical vocabulary: Part IV Electron tubes, Section 5 Pulse terms

1885 (Part IV/Sec 6)-1972 Electrotechnical vocabulary: Part IV Electron tubes, Section 6 Noise in microwave tubes

2032 (Part XIII)-1971 Graphical symbols used in electrotechnology: Part XIII Microwave tubes

5323-1969 Letter symbols and abbreviation for electron tubes

6134 (Part I/Sec 1)-1971 Methods of measurements on microwave tubes: Part I General measurements, Section 1 General conditions and precautions for measurements

6134 (Part I/Sec 2)-1972 Methods of measurements on microwave tubes: Part I General measurements, Section 2 Common to all devices

6134 (Part II)-1973 Methods of measurements on microwave tubes: Part II Oscillator tubes

6134 (Part III)-1973 Methods of measurements on microwave tubes: Part III Amplifier tubes

NOTE — For a complete list of Indian Standards on Electron Tubes, reference may be made to ISI Handbook.